Renewable and Sustainable Energy Reviews 16 (2012) 6128–6141

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Energy and fuel consumption forecast by retrofitting absorption cooling in Malaysia from 2012 to 2025

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ARTICLE INFO

Article history:
Received 10 August 2011
Received in revised form
28 June 2012
Accepted 15 July 2012
Available online 27 August 2012

Keywords:
Air conditioning
Absorption thermal system
Compression thermal system
Energy saving
Fuel consumption
Malaysia

ABSTRACT

Electricity demand in residential and commercial sectors has increased steadily over the past 50 years in Malaysia. The bulk of which is being consumed by air conditioning systems. Absorption cooling systems can be a reasonable alternative to have conditioned spaces in the country. The fuel consumption to produce electricity for cooling purposes in residential and commercial sectors has been forecasted from 2012 to 2025. The paper also investigates the effect of applying five different scenarios on energy and fuel consumption by retrofitting absorption chillers instead of conventional cooling systems. This study found that the consumption of natural gas will be raised by increase in utilized absorption chillers however, the consumption of different fuels such as coal, diesel and fuel oil will decrease in thermal power plants.

Contents

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1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2012.07.013

Nomenclature

Abs	Absorption cooling system
GE	Generated electricity (GW h)
CE	Consumed electricity (GW h)
CF	Consumed fuel (ton, m^3)
Com	Compression cooling system
CV	Calorific value (MJ/kg)
EC	Energy consumption (GW h)
FC	Fuel contribution
Q_H	Heating effect (MJ)
Q_L	Cooling effect (MJ)
SF	Share of each type of fuel (%)
SP	Share of each type of power plant (GW h)
η	Effciency
m	Mass of each fuel (kg)
ρ	Density (kg/m^3)

Subscripts

f	Fuel type consumed in power plant
i	In the year *i*

Superscripts

t	Type of power plant

1. Introduction

1.1. Energy supply and demand of Malaysia

Malaysian's main energy resources are crude oil, petroleum products, natural gas, coal and hydroelectric power plants. Recently, biomass has seen limited use as an alternative energy source [1–3].This is in part due to the supply of coal and coke increasing while there has been a sharp decrease in oil and petroleum products [4]. The sufficiency, security, reliability and cost-effectiveness of energy supplies in this country is coordinated by the Economic Planning Unit (EPU) and also coordinating the implementation of future power generation projects through a bidding process and a pilot plant on waste-to-energy. Certain projects pertaining to this field is discussed in Refs. [5–9]. Meanwhile the ministry of plantation industries and commodities is developing biofuel [10–12]. Programs related to the provision of reliable and cost-effective supply of energy and renewable energy in Malaysia is presented by Refs. [1,4,6,13–16].

1.2. Electricity generation in Malaysia

The electrical energy demand in Malaysia has increased tremendously in the past 3 decades, improving the energy conservation policy of Malaysia with it [17,18].

Malaysia's electricity power plants include conventional thermal, combined cycle, gas turbine, diesel, hydro, mini hydro and biomass. The country recently decided to utilize coal as the main source of fuel for power generation in an effort to reduce our dependence on oil and gas. In lieu of these 6420 MW (MW) of new generation capacity was installed [4].

1.3. Non-renewable power plants

Despite the Malaysian government's best efforts, most of the power plants in this country are using non-renewable sources such as coal, natural gases, diesel and fuel oil. Some examples of these power plants are steam turbine, combined cycle, gas turbine and diesel engine.

1.3.1. Steam turbine power plants

Steam turbine power plant uses high pressure steam to generate electricity. At present 32% of total electricity generation and 31% of total nominal capacity is produced by steam power plants. Efficiency of these power plants in Malaysia is 35% [18,19].

1.3.2. Gas turbine power plants

To generate electricity, natural gas can be used in Brayton cycle. Although the initial cost of these power plants is lower than steam turbines, their thermal efficiency is around 28.8%, which is much lower than combined cycle and steam turbine. Currently 3650 MW of nominal capacity and 17,245 GW h of electricity generation in Malaysia are produced by gas turbine power plants [19].

1.3.3. Combined cycle

In a gas turbine power plant, a high portion of energy is wasted through the expulsion of the exhaust gases; although, it is possible to transfer this energy to a Rankine cycle for electricity generation. Power plants that follow this method are called combined cycle plants. The thermal efficiency of combined cycles in Malaysia is 43.8%, making its efficiency higher than other fossil fuel power plants. Today, combined cycles plants in Malaysia have 8861 MW nominal capacity which is equivalent to 40.3% of the total capacity and produce 40.2% of the total electricity generated in the country [19].

1.3.4. Diesel engine power plants

These power plants usually operate in hospitals as a backup power source, as well as other industries that require a constant, uninterrupted power supply. 2% of nominal capacity and 1.8% of

electricity generation in Malaysia are from this type of power plants. The efficiency of diesel power plants is about 32% [19].

1.4. Renewable power plants

The primary energy source such as crude oil, natural gas and other conventional fuels are limited resources formed by geological processes through solar energy accumulation into the earth over millions of years [17]. Renewable energy is generated from renewable resources such as wind, solar, hydro, geothermal, biomass etc. Some works related to these renewable energy sources in Malaysia discussed deeply by Refs. [6,16,20–25]. Non-hydro renewable energy comprises about 5% of global power generating capacity and supplies 3.4% of global electricity production [26].

Malaysia is currently using renewable energy sources such as hydro and mini hydro for electricity production, the abidance of palm oil in Malaysia has also contributed to the use of biomass for electricity production in recent years. Generating electricity from oil mill wastes is discussed in Ref. [27].

1.4.1. Hydro power plants

From time to time hydro power has been used as a main renewable energy source. Although the initial cost of hydro power plants is higher than fossil fuel plants, their efficiency is generally higher and their life span is longer.

Malaysia has an average annual rainfall of 2000 mm, which is quite high compared to the average annual rainfall of the world (750 mm). Malaysia is considered as one of the potential countries for hydro-power plants, and 9.5% of nominal capacity and electricity generation in 2008 was from hydro-power plants [19].

1.4.2. Mini hydro-power plants

This type of power plant is being used to produce electricity in smaller scales such as for houses or small shops in remote area. Due to its smaller scale, it is unnecessary to construct a dam. Currently, mini hydro-power plants have 22 MW nominal capacities which is equivalent to 0.1% of total nominal capacities and produce 106 MW h of total energy generation [19].

1.5. Power plants fuel consumption

The type of fuel that is used for a power plant in a country depends on many factors, such as the economy, politics and technical parameters. These parameters include cost of the fuels, geographical location of the power plants, availability of the fuel, environmental concerns and medium and long-term policies of the energy sector. Most of Malaysian power generation is from thermal power plants that are using fossil fuels such as coal, natural gas, diesel and petroleum. Coal and natural gas are used widely for steam turbines while gas turbines and combined cycles use natural gas. Unlike fuel oil that is allocated to steam turbines, diesel is used in both gas turbines and diesel engines.

1.6. Energy policy in Malaysia

The per capita energy consumption of the majority of the population has increased considerably especially in developed countries [17]. The energy growth in developing countries has been increased rapidly due to major development in several sectors such as residential, commercial, industrial and transportation. The electrical energy consumption in Malaysia has increased greatly in the past few years; therefore there is a dire need for energy efficient technologies to be implemented as national energy policy [17]. The 9th Malaysian plan (2006–2010) emphasizes the security, reliability, and cost effectiveness of energy while focusing on the sustainable development of the energy sector [17]. Some of the recommended policies to be implemented in Malaysia are presented by Refs. [28–35].

Table 1
Malaysian electricity consumption by sectors.

Year	Residential and commercial (ktoe)	Industrial (ktoe)	Transport (toe)	Agriculture (toe)
1990	885	830	0	0
1991	988	937	0	0
1992	1081	1137	0	0
1993	1147	1303	0	0
1994	1365	1567	0	0
1995	1549	1826	0	0
1996	1747	2029	0	0
1997	1961	2422	1,000	0
1998	2165	2411	1,000	0
1999	2220	2591	4,000	0
2000	2453	2805	4,000	0
2001	2660	2930	5,000	0
2002	2859	3059	4,000	0
2003	3066	3242	5,000	0
2004	3298	3340	5,000	0
2005	3567	3371	5,000	0
2006	3792	3475	14,117	4,886
2007	4065	3587	15,295	15,991
2008	4268	3687	14,862	19,393

Table 1 shows the electricity consumption in different sectors in Malaysia from 1990 to 2008 [19,36–49]. As it can be seen in the table high amount of generated electricity is being consumed in residential and commercial sectors. Moreover the electricity consumption in all sectors is increasing during the years.

Generating more electricity by conventional nonrenewable power plants has its own challenges like more emission production, more fuel costs and more dependence to the countries that export oil. Malaysia has extensively implemented energy conservation in order to reduce consumption growth rate. Some of energy conservation programs in the country are deeply discussed by Refs. [1,9,29,50–54].

Absorption systems can be a reasonable alternative in order to reduce the electricity consumption in residential and commercial sectors by conventional cooling systems [55].

1.7. Absorption and compression chillers

Absorption cycles have been used in air-conditioning applications for over 50 years. Ammonia–water absorption equipment was found to be well suited for large capacity industrial applications that required low temperatures for process cooling. In the late 1950s the first working double-effect lithium bromide–water absorption chiller was built. Lithium bromide–water absorption equipment is currently used to produce chilled water for space cooling and can also be used to produce hot water for space heating and process heating. Absorption chiller is a popular alternative for conventional compression chillers when electricity is unreliable, costly, or unavailable [56].

Absorption chillers are generally classified as direct- or indirect-fired, and as single, double or triple-effect. In direct-fired units, the heat source can be gas or some other fuel that is burned in the unit. In general, increasing the number of effects is intended to increase the COP using higher driving temperature levels [56–58]. The primary energy benefit of gas cooling systems is reduction in operating costs by avoiding peak electric demand charges and time-of-day rates. The use of gas absorption chillers eliminates the high incremental cost of electric cooling [56].

Natural gas cooling systems have greater resource efficiency than other similar electric systems. Typical electricity generation and distribution result in an approximately 65–75% loss in the

initial energy resource of the fuel. In contrast, only 5% to 10% of the fuel resource is lost with a gas system. Additionally, electricity costs per kW are typically three to four times more than cost per kW h for natural gas, so the cost of a unit of output (refrigeration) can often be lower with an absorption unit [56]. Some of the works on thermodynamics and/or economic analyses of absorption chillers are given in Refs. [59–61].

Waste energies and renewable recourses can be used to drive absorption chillers. An analysis of using solar absorption chillers for residential cooling instead of compression chillers in order to save electricity and fossil resources consequently is presented by Ref. [62]. Some of the released works on this area can be found in Refs. [63–69]. Using wasted heat of gas-turbines' exhausts to drive absorption chillers by investigating the efficiency and cost saving of gas turbines while the absorption system is cooling the compressor's entrance air has been discussed by Ref. [70]. Unfortunately the COP of absorption chillers is much less than compression chillers. Some modeling investigations and augmentations of COP related to absorption chillers are widely discussed in Refs. [71–74]. Since COP individually is not a sufficient criterion to choose between absorption and compression chillers for cooling an area; HVAC engineers are using integrated part load value (IPLV) and applied part load value (APLV). IPLV is an industry standard for calculating an annual COP based on a typical load profile and the part load characteristics of chillers. The applied part load value, APLV is calculated using the same IPLV formula, except that actual chilled and condenser water temperatures and flow rates are used. The advantage of using the APLV over the IPLV is that this rating more closely approximates actual operating conditions imposed on the chillers [56].

In order to compare compression and absorption chillers in energy consumption point of view in Malaysia, five scenarios have been investigated in this research. Today, there are many types of absorption chillers in the market. They vary in size and COP as well as cost. Based on these, this paper presents the annual amount of each type of required fuel for cooling from 1990 to 2008, the required energy for cooling for the next 17 years starting from 2012 to 2025 and also the annual amount of each type of fuel required for cooling in the forecasted period for each scenario. The results reveal the consumption of each type of fuel in each scenario so that it can be a useful guideline for retrofitting of the compression cooling systems in Malaysia.

In this research, five scenarios have been investigated in order to compare compression and absorption chillers in energy consumption point of view in Malaysia. Each scenario proposes a combination of compression and absorption systems to supply the cooling load of the country. The required amount of fuel and energy to utilize absorption and compression cycles for the country has been calculated.

2. Survey data

The data used for this study are based on electricity generation in Malaysia, fossil fuel used to produce electricity in power plants, and electricity consumption in residential and commercial sectors from 1990 to 2009. These data collected and extracted from Refs. [19,36–49] and tabulated in Tables 1–3.

3. Methodology

3.1. Scenarios of air-conditioned system from 2012 to 2025

The scenarios are tools for ordering perceptions about alternative future environments and the result might not be an accurate picture of tomorrow, but may give a better decision about the future. Regardless of how things could actually be, both the analyst and the decision maker will have a scenario that resembles a given future and will help researchers consider both possibilities and consequences of the future [75]. In doing so, the future Air conditioning systems composition presented in five different scenarios.

Table 2
Percentage of Malaysian electricity consumption by sectors.

Year	Residential and commercial	Industrial	Transport	Agriculture
1990	51.6	48.4	0.0	0.0
1991	51.3	48.6	0.0	0.0
1992	48.7	51.2	0.0	0.0
1993	46.8	53.1	0.0	0.0
1994	46.5	53.4	0.0	0.0
1995	45.9	54.1	0.0	0.0
1996	46.2	53.7	0.0	0.0
1997	44.7	55.2	0.0	0.0
1998	47.3	52.6	0.0	0.0
1999	46.1	53.8	0.1	0.0
2000	46.6	53.3	0.1	0.0
2001	47.5	52.3	0.1	0.0
2002	48.2	51.6	0.1	0.0
2003	48.5	51.3	0.1	0.0
2004	49.6	50.2	0.1	0.0
2005	51.3	48.5	0.1	0.0
2006	52.0	47.7	0.2	0.0
2007	52.9	46.7	0.2	0.0
2008	53.4	46.1	0.2	0.0

Table 3
Essential input data.

Description	Values (MJ/m^3)
Natural gas calorific value	40
Coal calorific value	27
Diesel oil calorific value	44.8
Fuel oil calorific value	47.3

3.1.1. Five different scenarios

From the year 2012 until 2025, five different scenarios are assumed which can be performed to provide the required cooling load of Malaysia. In all these scenarios, two assumptions are applied, the first one is that the contribution of power plants for the electricity generation between 2012 and 2025 are constant and it is the same as the year 2008. In another word it was assumed, Malaysia will increase the generated electricity by increase in number of power plants but the share of each type of power plant will not be affected. The second assumption is that the share of consuming fuels in each type of power plant also will be fixed during the forecasting period and it is also as same as the year 2008.

The first scenario is using the same air-conditioned systems to supply the cooling load in the future. So 100% of the cooling load in this scenario should be supplied by compression chillers. The second scenario is using compression chillers for 75% of the cooling load and using absorption chillers to supply the rest 25%. The next scenario is using the same contribution for the absorption and compression chillers (50% compression and 50% absorption). In the fourth and fifth scenarios, the contribution of absorption chillers is increased to 75% and 100%, respectively.

3.2. Electricity and fuel consumption

3.2.1. Residential and commercial electricity consumption

As it is mentioned in the survey data, the residential and commercial electricity consumption is obtained from National

Energy Balance Malaysia [19,42–49]. It is assumed that 70% of the consumption in these two sectors is due to air-conditioned systems. So in the first step, the consumption of air-conditioned systems from 1990 to 2008 is calculated.

3.2.2. Electricity generation in each type of power plant in each year

The generated electricity for air-conditioned systems from power plant type *t*, in year *i* can be calculated by the following equation:

$$GE_i^t = CE_i \times SP_i^t \quad (1)$$

3.2.3. Energy consumption in power plants

The energy consumption in each type of power plants can be expressed by:

$$EC_i^t = \frac{GE_i^t}{\eta^t} \quad (2)$$

The total consumed energy for cooling can be obtained by the following equation:

$$EC_i = \sum_t EC_i^t \quad (3)$$

3.2.4. Fuel contribution

The share of each fuel in the electricity generation is obtained from the National Energy Balance Malaysia [19,42–49]. Contribution of fuel f in generated electricity for cooling in year *i* calculated by:

$$FC_i^f = EC_i \times SF_i^f \quad (4)$$

Quantity of different fuels can be calculated by their calorific value and their density with the following equation; the density of natural gas, diesel oil and fuel oil are assumed 0.8, 832 and 900 (kg/m3), respectively:

$$CF_i = \frac{FC_i^f}{CV^f \times \rho^f} \quad (5)$$

3.2.5. Natural gas consumption for absorption chillers

The consumption of natural gas for absorption chillers in different scenarios for the forecasting period can be calculated by following equation:

$$COP_{abs/com} = \frac{Q_{Li}}{Q_{H_i}} \quad (6)$$

$$Q_{H_i} = CV_{NG} \times m_i \quad (7)$$

In these calculations, the compression and absorption chillers COPs are assumed to be 2.9 and 0.9, respectively [55]. As it can be seen, the pump work in absorption chillers has been considered to be negligible [58].

3.3. Method of data estimation

Some data are available but others have to be estimated. The required electricity for air-conditioned systems in each year from 2009 to 2025 can be estimated. There are several methods for estimating data; the one that is widely used is polynomial curve fitting. This method tries to describe the relationship between a variable *X* as the function of available data and a response *Y* that seeks to find a smooth curve for the best fit of the data. Mathematically, a polynomial of order *k* in *X* can be expressed in the following equation form Ref. [76]:

$$Y = C_0 + C_1X + C_2X^2 + \cdots + C_kX^k \quad (8)$$

4. Results and discussion

4.1. Electricity consumption in air-conditioning systems from 1990 to 2025

As it can be seen in Table 4, the electricity consumption for air-conditioning purpose had a steady upward trend in previous years. Consequently, the energy consumption and also the fuel demand to produce the desired electricity had been increasing. The consumption of different kinds of fuels for previous years is calculated and demonstrated in Table 5 in respect to two

Table 4
Electricity consumption by air conditioning systems from 1990 to 2008 in Malaysia.

Year	Electricity consumption (GW h)
1990	7,204.8
1991	8,043.3
1992	8,800.4
1993	9,337.7
1994	11,112.5
1995	12,610.4
1996	14,222.3
1997	15,964.5
1998	17,625.3
1999	18,073.0
2000	19,969.9
2001	21,655.1
2002	23,275.1
2003	24,960.3
2004	26,849.0
2005	29,038.9
2006	30,870.7
2007	33,093.2
2008	34,745.8

Table 5
Composition of fuel consumption (Mm^3, km^3 and kton) by using compression chillers from 1990 to 2008.

Year	Fuel type	Compression chillers
1990	Coal (kton)	24.35
	Natural gas (Mm^3)	1176.28
	Diesel (km^3)	5.88
	Fuel oil (km^3)	19.31
1992	Coal (kton)	81.44
	Natural gas (Mm^3)	1490.31
	Diesel (km^3)	11.06
	Fuel oil (km^3)	35.51
1993	Coal (kton)	117.74
	Natural gas (Mm^3)	1635.64
	Diesel (km^3)	13.88
	Fuel oil (km^3)	36.47
1994	Coal (kton)	171.65
	Natural gas (Mm^3)	1997.00
	Diesel (km^3)	26.30
	Fuel oil (km^3)	48.15
1995	Coal (kton)	206.07
	Natural gas (Mm^3)	2272.95
	Diesel (km^3)	21.71
	Fuel oil (km^3)	52.28
1996	Coal (kton)	286.55
	Natural gas (Mm^3)	2551.25
	Diesel (km^3)	27.88
	Fuel oil (km^3)	94.94
1997	Coal (kton)	305.50
	Natural gas (Mm^3)	2921.30

Table 5 (*continued*)

Year	Fuel type	Compression chillers
	Diesel (km^3)	38.64
	Fuel oil (km^3)	138.40
1998	Coal (kton)	385.23
	Natural gas (Mm^3)	3245.88
	Diesel (km^3)	42.63
	Fuel oil (km^3)	152.71
1999	Coal (kton)	440.21
	Natural gas (Mm^3)	3379.95
	Diesel (km^3)	39.86
	Fuel oil (km^3)	150.07
2000	Coal (kton)	581.53
	Natural gas (Mm^3)	3788.78
	Diesel (km^3)	52.11
	Fuel oil (km^3)	144.49
2001	Coal (kton)	771.30
	Natural gas (Mm^3)	3893.86
	Diesel (km^3)	79.15
	Fuel oil (km^3)	179.37
2002	Coal (kton)	950.49
	Natural gas (Mm^3)	3929.68
	Diesel (km^3)	127.87
	Fuel oil (km^3)	322.95
2003	Coal (kton)	1772.13
	Natural gas (Mm^3)	3969.06
	Diesel (km^3)	78.27
	Fuel oil (km^3)	105.09
2004	Coal (kton)	2288.47
	Natural gas (Mm^3)	3823.17
	Diesel (km^3)	88.41
	Fuel oil (km^3)	72.57
2005	Coal (kton)	2302.67
	Natural gas (Mm^3)	4368.86
	Diesel (km^3)	90.16
	Fuel oil (km^3)	73.68
2006	Coal (kton)	2608.63
	Natural gas (Mm^3)	4546.77
	Diesel (km^3)	196.15
	Fuel oil (km^3)	45.80
2007	Coal (kton)	3370.78
	Natural gas (Mm^3)	4706.89
	Diesel (km^3)	99.95
	Fuel oil (km^3)	56.26
2008	Coal (kton)	3448.18
	Natural gas (Mm^3)	4921.59
	Diesel (km^3)	89.74
	Fuel oil (km^3)	45.84

important factors; the first one is the contribution of different kinds of power plants (with different efficiencies) in electricity generation and another one is the fuel consumption contribution in each year. The results show that the consumption of all different types of fuels has been increased during this period. Mostly, natural gas is considered as the highest consumed fuel in compare with the other three fuels but the consumption rate of the natural gas is decreasing from 1990 to 2008. On the other hand, the consumption of coal was increasing steadily as it is shown in Fig. 1.

The electricity consumption for air-conditioning systems can be predicted by Eq. (1). By using the data from 1990 to 2008, the electricity consumption for air-conditioning systems is predicted and illustrated in Fig. 2. It is clear that the demand for air-conditioning electricity consumption is increasing gradually due to population growth. Thus, increase in the consumption of four types of fossil fuels is inevitable.

$$Y = 30.09x^2 + 1019x + 6823, \quad R^2 = 0.998 \tag{9}$$

4.2. Composition of fuel consumption for cooling systems in different scenarios

The results show that the consumed electricity that is generated from natural gas is much higher than the other fossil fuels resources. This is due to the tendency to use more natural gas as fuel in power plants. In the first scenario, it is assumed that all the cooling systems are normal compression chillers which are being used nowadays. As it is illustrated in Table 6, the consumption of all kinds of fuels is increased and this is due to increasing in consumption of electricity in air-conditioned systems.

From 2012 to 2025, there is about 322.9 (Mm^3/year) increase in the consumption of natural gas while the consumption of coal, diesel and fuel oil will increase by 226.26 (kton/year), 5.89 (km^3/year) and 3.01 (km^3/year), respectively.

In the next scenario, 25% of the cooling load will be supplied by absorption chillers, thus the consumed natural gas to provide the same cooling load during the period is increased while the consumption of coal, diesel and fuel oil is decreased slightly. The result for this scenario is demonstrated in Table 7. ;In compare with the previous scenario, the consumption of natural gas is increased by 118.9 (Mm^3/year), while the consumption of coal, diesel and fuel decreased by 56.6 (kton/year), 1.5 (km^3/year) and 0.76 (km^3/year), respectively.

Similarly, in the next three scenarios there will be a steady upward trend in consumption of natural gas, while the

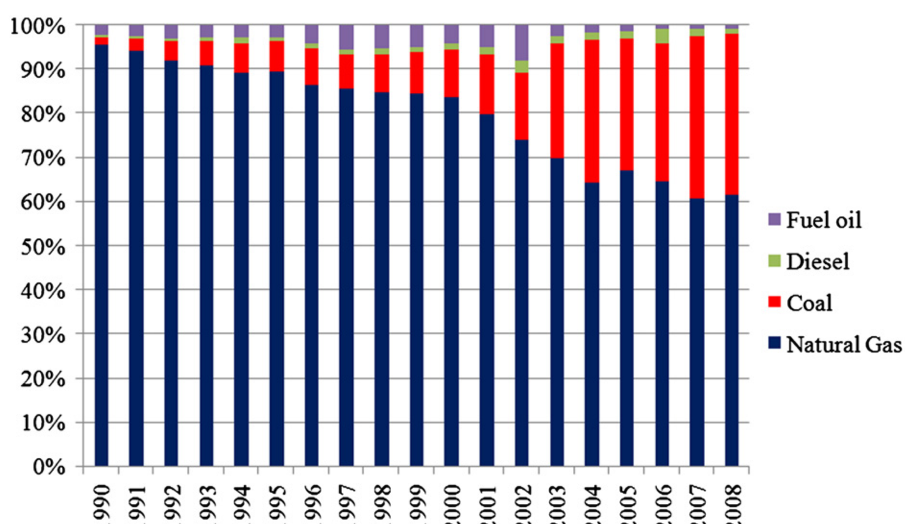


Fig. 1. The contribution of each fuel to produce the desired consumed electricity for the air-conditioning systems.

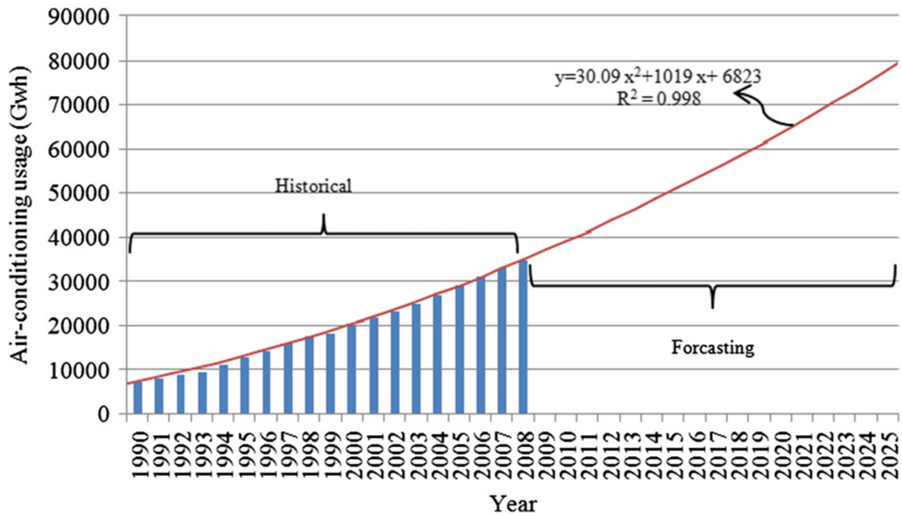


Fig. 2. Historical and forecasted consumed electricity for air-conditioning systems in Malaysia from 1990 to 2025.

Table 6
Composition of fuel consumption (Mm^3, km^3 and kton) in scenario 1 from 2012 to 2020.

Year	Fuel type	Compression chillers	Total
2012	Coal (kton)	4005.23	4005.23
	Natural gas (Mm^3)	5716.67	5716.67
	Diesel (km^3)	104.24	104.24
	Fuel oil (km^3)	53.24	53.24
2013	Coal (kton)	4209.82	4209.82
	Natural gas (Mm^3)	6008.68	6008.68
	Diesel (km^3)	109.56	109.56
	Fuel oil (km^3)	55.96	55.96
2014	Coal (kton)	4419.23	4419.23
	Natural gas (Mm^3)	6307.57	6307.57
	Diesel (km^3)	115.01	115.01
	Fuel oil (km^3)	58.74	58.74
2015	Coal (kton)	4633.45	4633.45
	Natural gas (Mm^3)	6613.33	6613.33
	Diesel (km^3)	120.59	120.59
	Fuel oil (km^3)	61.59	61.59
2016	Coal (kton)	4852.49	4852.49
	Natural gas (Mm^3)	6925.96	6925.96
	Diesel (km^3)	126.29	126.29
	Fuel oil (km^3)	64.50	64.50
2017	Coal (kton)	5076.34	5076.34
	Natural gas (Mm^3)	7245.46	7245.46
	Diesel (km^3)	132.11	132.11
	Fuel oil (km^3)	67.48	67.48
2018	Coal (kton)	5305.00	5305.00
	Natural gas (Mm^3)	7571.83	7571.83
	Diesel (km^3)	138.06	138.06
	Fuel oil (km^3)	70.52	70.52
2019	Coal (kton)	5538.48	5538.48
	Natural gas (Mm^3)	7905.08	7905.08
	Diesel (km^3)	144.14	144.14
	Fuel oil (km^3)	73.62	73.62
2020	Coal (kton)	3420.33	3420.33
	Natural gas (Mm^3)	4881.84	4881.84
	Diesel (km^3)	89.02	89.02
	Fuel oil (km^3)	45.47	45.47
2021	Coal (kton)	3610.48	3610.48
	Natural gas (Mm^3)	5153.24	5153.24
	Diesel (km^3)	93.96	93.96
	Fuel oil (km^3)	47.99	47.99
2022	Coal (kton)	3805.45	3805.45
	Natural gas (Mm^3)	5431.52	5431.52

Table 6 (*continued*)

Year	Fuel type	Compression chillers	Total
	Diesel (km^3)	99.04	99.04
	Fuel oil (km^3)	50.58	50.58
2023	Coal (kton)	4005.23	4005.23
	Natural gas (Mm^3)	5716.67	5716.67
	Diesel (km^3)	104.24	104.24
	Fuel oil (km^3)	53.24	53.24
2024	Coal (kton)	4209.82	4209.82
	Natural gas (Mm^3)	6008.68	6008.68
	Diesel (km^3)	109.56	109.56
	Fuel oil (km^3)	55.96	55.96
2025	Coal (kton)	4419.23	4419.23
	Natural gas (Mm^3)	6307.57	6307.57
	Diesel (km^3)	115.01	115.01
	Fuel oil (km^3)	58.74	58.74

Table 7
Composition of fuel consumption (Mm^3, km^3 and kton) in scenario 2 from 2012 to 2020.

Year	Fuel type	Compression chillers	Absorption chillers	Total
2012	Coal (kton)	3003.92	–	3,003.92
	Natural gas (Mm^3)	4287.50	3657.53	7,945.03
	Diesel (km^3)	78.18	–	78.18
	Fuel oil (km^3)	39.93	–	39.93
2013	Coal (kton)	3157.36	–	3,157.36
	Natural gas (Mm^3)	4506.51	3844.36	8,350.87
	Diesel (km^3)	82.17	–	82.17
	Fuel oil (km^3)	41.97	–	41.97
2014	Coal (kton)	3314.42	–	3,314.42
	Natural gas (Mm^3)	4730.68	4035.59	8,766.27
	Diesel (km^3)	86.26	–	86.26
	Fuel oil (km^3)	44.06	–	44.06
2015	Coal (kton)	3475.09	–	3,475.09
	Natural gas (Mm^3)	4960.00	4231.21	9,191.21
	Diesel (km^3)	90.44	–	90.44
	Fuel oil (km^3)	46.19	–	46.19
2016	Coal (kton)	3639.36	–	3,639.36
	Natural gas (Mm^3)	5194.47	4431.23	9,625.70
	Diesel (km^3)	94.72	–	94.72
	Fuel oil (km^3)	48.38	–	48.38
2017	Coal (kton)	3807.25	–	3,807.25
	Natural gas (Mm^3)	5434.10	4635.65	10,069.75
	Diesel (km^3)	99.09	–	99.09
	Fuel oil (km^3)	50.61	–	50.61
2018	Coal (kton)	3978.75	–	3,978.75
	Natural gas (Mm^3)	5678.88	4844.46	10,523.34
	Diesel (km^3)	103.55	–	103.55
	Fuel oil (km^3)	52.89	–	52.89
2019	Coal (kton)	4153.86	–	4,153.86
	Natural gas (Mm^3)	5928.81	5057.67	10,986.48
	Diesel (km^3)	108.11	–	108.11
	Fuel oil (km^3)	55.22	–	55.22
2020	Coal (kton)	4332.58	–	4,332.58
	Natural gas (Mm^3)	6183.89	5275.28	11,459.17
	Diesel (km^3)	112.76	–	112.76
	Fuel oil (km^3)	57.59	–	57.59
2021	Coal (kton)	4514.91	–	4,514.91
	Natural gas (Mm^3)	6444.13	5497.28	11,941.41
	Diesel (km^3)	117.50	–	117.50
	Fuel oil (km^3)	60.02	–	60.02
2022	Coal (kton)	4700.85	–	4,700.85
	Natural gas (Mm^3)	6709.52	5723.68	12,433.20
	Diesel (km^3)	122.34	–	122.34
	Fuel oil (km^3)	62.49	–	62.49
2023	Coal (kton)	4890.40	–	4,890.40
	Natural gas (Mm^3)	6980.07	5954.47	12,934.54

Table 7 (*continued*)

Year	Fuel type	Compression chillers	Absorption chillers	Total
	Diesel (km^3)	127.27	–	127.27
	Fuel oil (km^3)	65.01	–	65.01
2024	Coal (kton)	5083.56	–	5,083.56
	Natural gas (Mm^3)	7255.77	6189.66	13,445.43
	Diesel (km^3)	132.30	–	132.30
	Fuel oil (km^3)	67.57	–	67.57
2025	Coal (kton)	5280.33	–	5,280.33
	Natural gas (Mm^3)	7536.62	6317.15	13,853.77
	Diesel (km^3)	137.42	–	137.42
	Fuel oil (km^3)	70.19	–	70.19

Table 8
Composition of fuel consumption (Mm^3, km^3 and kton) in scenario 3 from 2012 to 2020.

Year	Fuel type	Compression chillers	Absorption chillers	Total
2012	Coal (kton)	2002.61	–	2,002.61
	Natural gas (Mm^3)	2858.33	7,315.05	10,173.39
	Diesel (km^3)	52.12	–	52.12
	Fuel oil (km^3)	26.62	–	26.62
2013	Coal (kton)	2104.91	–	2,104.91
	Natural gas (Mm^3)	3004.34	7,688.72	10,693.06
	Diesel (km^3)	54.78	–	54.78
	Fuel oil (km^3)	27.98	–	27.98
2014	Coal (kton)	2209.61	–	2,209.61
	Natural gas (Mm^3)	3153.79	8,071.18	11,224.96
	Diesel (km^3)	57.51	–	57.51
	Fuel oil (km^3)	29.37	–	29.37
2015	Coal (kton)	2316.72	–	2316.72
	Natural gas (Mm^3)	3306.67	8,462.43	11,769.09
	Diesel (km^3)	60.29	–	60.29
	Fuel oil (km^3)	30.80	–	30.80
2016	Coal (kton)	2426.24	–	2,426.24
	Natural gas (Mm^3)	3462.98	8,862.47	12,325.45
	Diesel (km^3)	63.14	–	63.14
	Fuel oil (km^3)	32.25	–	32.25
2017	Coal (kton)	2538.17	–	2,538.17
	Natural gas (Mm^3)	3622.73	9,271.30	12,894.03
	Diesel (km^3)	66.06	–	66.06
	Fuel oil (km^3)	33.74	–	33.74
2018	Coal (kton)	2652.50	–	2,652.50
	Natural gas (Mm^3)	3785.92	9,688.93	13,474.85
	Diesel (km^3)	69.03	–	69.03
	Fuel oil (km^3)	35.26	–	35.26
2019	Coal (kton)	2769.24	–	2,769.24
	Natural gas (Mm^3)	3952.54	10,115.35	14,067.89
	Diesel (km^3)	72.07	–	72.07
	Fuel oil (km^3)	36.81	–	36.81
2020	Coal (kton)	2888.38	–	2,888.38
	Natural gas (Mm^3)	4122.60	10,550.56	14,673.15
	Diesel (km^3)	75.17	–	75.17
	Fuel oil (km^3)	38.39	–	38.39
2021	Coal (kton)	3009.94	–	3,009.94
	Natural gas (Mm^3)	4296.09	10,994.56	15,290.65
	Diesel (km^3)	78.33	–	78.33
	Fuel oil (km^3)	40.01	–	40.01
2022	Coal (kton)	3133.90	–	3,133.90
	Natural gas (Mm^3)	4473.02	11,447.36	15,920.37
	Diesel (km^3)	81.56	–	81.56
	Fuel oil (km^3)	41.66	–	41.66
2023	Coal (kton)	3260.26	–	3,260.26
	Natural gas (Mm^3)	4653.38	11,908.94	16,562.32
	Diesel (km^3)	84.85	–	84.85
	Fuel oil (km^3)	43.34	–	43.34
2024	Coal (kton)	3389.04	–	3,389.04
	Natural gas (Mm^3)	4837.18	12,379.32	17,216.50
	Diesel (km^3)	88.20	–	88.20

Table 8 (*continued*)

Year	Fuel type	Compression chillers	Absorption chillers	Total
	Fuel oil (km^3)	45.05	–	45.05
2025	Coal (kton)	3520.22	–	3,520.22
	Natural gas (Mm^3)	5024.41	12,634.29	17,658.71
	Diesel (km^3)	91.62	–	91.62
	Fuel oil (km^3)	46.79	–	46.79

Table 9
Composition of fuel consumption (Mm^3, km^3 and kton) in scenario 4 from 2012 to 2020.

Year	Fuel type	Compression chillers	Absorption chillers	Total
2012	Coal (kton)	1001.31	–	1,001.31
	Natural gas (Mm^3)	1429.17	10,972.58	12,401.75
	Diesel (km^3)	26.06	–	26.06
	Fuel oil (km^3)	13.31	–	13.31
2013	Coal (kton)	1052.45	–	1,052.45
	Natural gas (Mm^3)	1502.17	11,533.08	13,035.25
	Diesel (km^3)	27.39	–	27.39
	Fuel oil (km^3)	13.99	–	13.99
2014	Coal (kton)	1104.81	–	1,104.81
	Natural gas (Mm^3)	1576.89	12,106.77	13,683.66
	Diesel (km^3)	28.75	–	28.75
	Fuel oil (km^3)	14.69	–	14.69
2015	Coal (kton)	1158.36	–	1,158.36
	Natural gas (Mm^3)	1653.33	12,693.64	14,346.97
	Diesel (km^3)	30.15	–	30.15
	Fuel oil (km^3)	15.40	–	15.40
2016	Coal (kton)	1213.12	–	1,213.12
	Natural gas (Mm^3)	1731.49	13,293.70	15,025.19
	Diesel (km^3)	31.57	–	31.57
	Fuel oil (km^3)	16.13	–	16.13
2017	Coal (kton)	1269.08	–	1,269.08
	Natural gas (Mm^3)	1811.37	13,906.95	15,718.32
	Diesel (km^3)	33.03	–	33.03
	Fuel oil (km^3)	16.87	–	16.87
2018	Coal (kton)	1326.25	–	1,326.25
	Natural gas (Mm^3)	1892.96	14,533.39	16,426.35
	Diesel (km^3)	34.52	–	34.52
	Fuel oil (km^3)	17.63	–	17.63
2019	Coal (kton)	1384.62	–	1,384.62
	Natural gas (Mm^3)	1976.27	15,173.02	17,149.29
	Diesel (km^3)	36.04	–	36.04
	Fuel oil (km^3)	18.41	–	18.41
2020	Coal (kton)	1444.19	–	1,444.19
	Natural gas (Mm^3)	2061.30	15,825.84	17,887.14
	Diesel (km^3)	37.59	–	37.59
	Fuel oil (km^3)	19.20	–	19.20
2021	Coal (kton)	1504.97	–	1,504.97
	Natural gas (Mm^3)	2148.04	16,491.84	18,639.89
	Diesel (km^3)	39.17	–	39.17
	Fuel oil (km^3)	20.01	–	20.01
2022	Coal (kton)	1566.95	–	1,566.95
	Natural gas (Mm^3)	2236.51	17,171.03	19,407.54
	Diesel (km^3)	40.78	–	40.78
	Fuel oil (km^3)	20.83	–	20.83
2023	Coal (kton)	1630.13	–	1,630.13
	Natural gas (Mm^3)	2326.69	17,863.41	20,190.10
	Diesel (km^3)	42.42	–	42.42
	Fuel oil (km^3)	21.67	–	21.67
2024	Coal (kton)	1694.52	–	1,694.52
	Natural gas (Mm^3)	2418.59	18,568.98	20,987.57
	Diesel (km^3)	44.10	–	44.10
	Fuel oil (km^3)	22.52	–	22.52
2025	Coal (kton)	1760.11	–	1,760.11
	Natural gas (Mm^3)	2512.21	18,951.44	21,463.65
	Diesel (km^3)	45.81	–	45.81
	Fuel oil (km^3)	23.40	–	23.40

consumption of the other fossil fuels is declined. The results are illustrated in Tables 8–10.

In compare with Table 6 which shows the results for the conventional air conditioning systems, Table 10 shows the fuel consumption if all the air conditioning systems in the residential sector will be retrofitted with the absorption cycles. For year 2025 the natural gas consumption will be 6307.57 and 25,268.59 Mm^3 in scenario 1 and 5, respectively. Based on the investigation, consumption of coal in order to cooling in year 2025 will decrease from 4419.23 kton to zero in scenario1 and 5, respectively.

Fig.3 shows the percentage of consumed energy for cooling which is provided by different type of fuels in different scenarios. As it can be seen in the graph, by changing the scenarios from one to five, mostly the consumed energy will be provided by natural gas, thus the consumption of the other fossil fuels is decreased. In

Table 10
Composition of fuel consumption (Mm^3, km^3 and kton) in scenario 5 from 2012 to 2020.

Year	Fuel type	Absorption chillers	Total
2012	Coal (kton)	–	0.00
	Natural gas (Mm^3)	14,630.11	14,630.11
	Diesel (km^3)	–	0.00
	Fuel oil (km^3)	–	0.00
2013	Coal (kton)	–	0.00
	Natural gas (Mm^3)	15,377.44	15,377.44
	Diesel (km^3)	–	0.00
	Fuel oil (km^3)	–	0.00
2014	Coal (kton)	–	0.00
	Natural gas (Mm^3)	16,142.35	16,142.35
	Diesel (km^3)	–	0.00
	Fuel oil (km^3)	–	0.00
2015	Coal (kton)	–	0.00
	Natural gas (Mm^3)	16,924.85	16,924.85
	Diesel (km^3)	–	0.00
	Fuel oil (km^3)	–	0.00
2016	Coal (kton)	–	0.00
	Natural gas (Mm^3)	17,724.94	17,724.94
	Diesel (km^3)	–	0.00
	Fuel oil (km^3)	–	0.00
2017	Coal (kton)	–	0.00
	Natural gas (Mm^3)	18,542.61	18,542.61
	Diesel (km^3)	–	0.00
	Fuel oil (km^3)	–	0.00
2018	Coal (kton)	–	0.00
	Natural gas (Mm^3)	19,377.86	19,377.86
	Diesel (km^3)	–	0.00
	Fuel oil (km^3)	–	0.00
2019	Coal (kton)	–	0.00
	Natural gas (Mm^3)	20,230.70	20,230.70
	Diesel (km^3)	–	0.00
	Fuel oil (km^3)	–	0.00
2020	Coal (kton)	–	0.00
	Natural gas (Mm^3)	21,101.12	21,101.12
	Diesel (km^3)	–	0.00
	Fuel oil (km^3)	–	0.00
2021	Coal (kton)	–	0.00
	Natural gas (Mm^3)	21,989.12	21,989.12
	Diesel (km^3)	–	0.00
	Fuel oil (km^3)	–	0.00
2022	Coal (kton)	–	0.00
	Natural gas (Mm^3)	22,894.71	22,894.71
	Diesel (km^3)	–	0.00
	Fuel oil (km^3)	–	0.00
2023	Coal (kton)	–	0.00
	Natural gas (Mm^3)	23,817.89	23,817.89
	Diesel (km^3)	–	0.00
	Fuel oil (km^3)	–	0.00
2024	Coal (kton)	–	0.00
	Natural gas (Mm^3)	24,758.64	24,758.64
	Diesel (km^3)	–	0.00
	Fuel oil (km^3)	–	0.00
2025	Coal (kton)	–	0.00
	Natural gas (Mm^3)	25,268.59	25,268.59
	Diesel (km^3)	–	0.00
	Fuel oil (km^3)	–	0.00

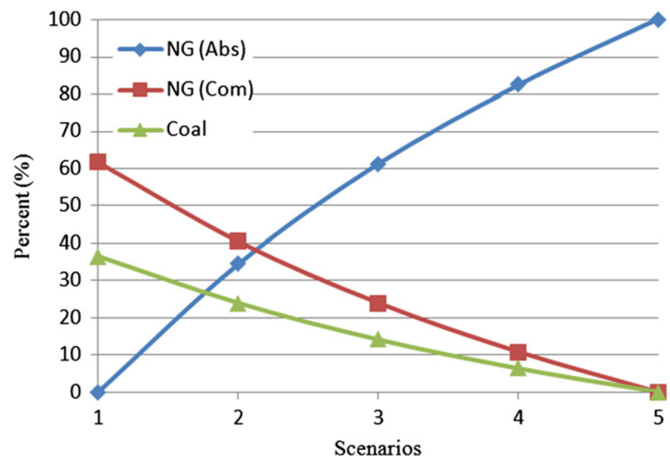


Fig. 3. The percentage of cooling load provided by different types of fuels in different scenarios.

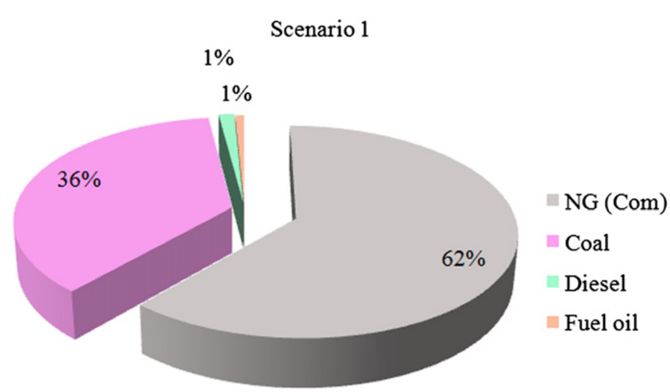


Fig. 4. The percentage of fuel consumption to provide the desire cooling energy in scenario 1.

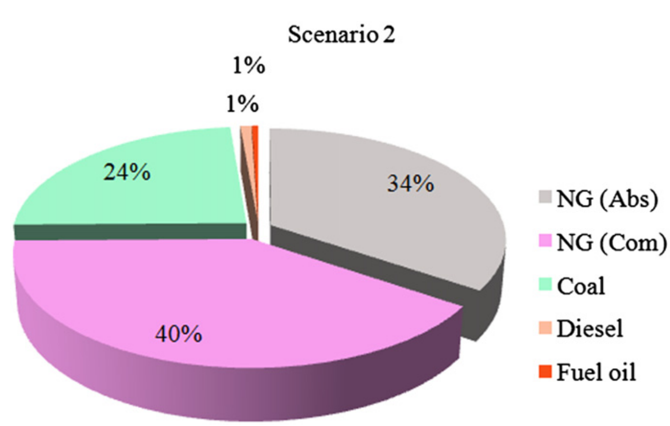


Fig. 5. The percentage of fuel consumption to provide the desire cooling energy in scenario 2.

addition, since the consumption of diesel fuel and fuel oil was negligible, these percentages have not been figured.

4.3. The portion of consumed fuel in each scenario

The percentage of fuel consumption in each scenario is demonstrated in Figs.4–7. As it is shown there, in the first scenario, the consumption of coal, diesel and fuel oil are higher than the other scenarios and it is due to the use of compression chillers as the main cooling systems for air-conditioned buildings. In the last scenario which is not shown below the only type of consumed fuel will be natural gas for cooling purpose in residential and commercial sector. In the third scenario, the consumption of fuel oil is negligible and similarly in the forth scenario, the consumption of diesel and fuel oil will be negligible. The results of these two scenarios are shown in Figs. 6 and 7. Fig. 8 illustrates the contribution of each fuel for cooling in different scenarios for absorption and compression cooling systems. It is clear that when the scenarios changed from one to five, the consumption of natural gas consumed by absorption chillers is increased and conversely the consumption of the other fuels will decrease.

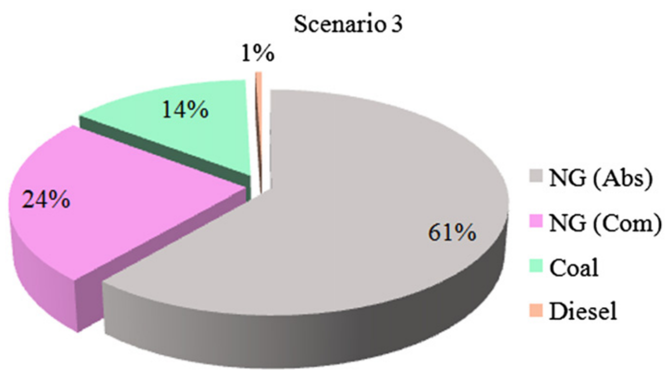


Fig. 6. The percentage of fuel consumption to provide the desire cooling energy in scenario 3.

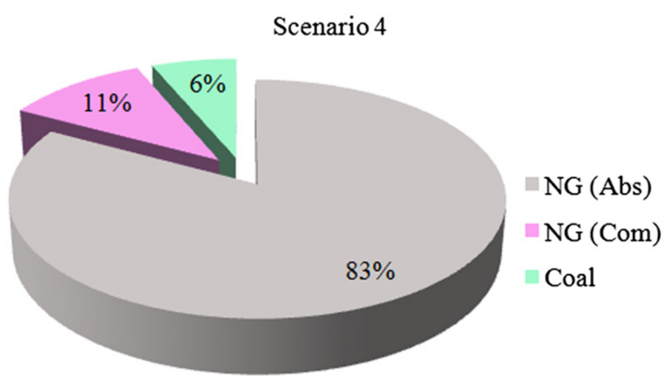


Fig. 7. The percentage of fuel consumption to provide the desire cooling energy in scenario 4.

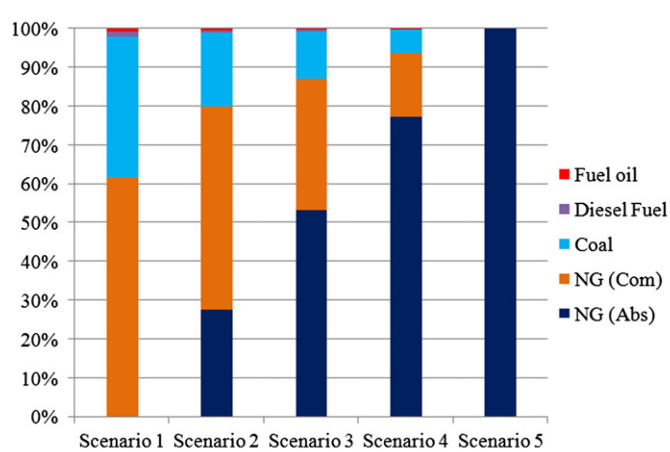


Fig. 8. The percentage of fuel consumption to provide the desire cooling energy in different scenarios.

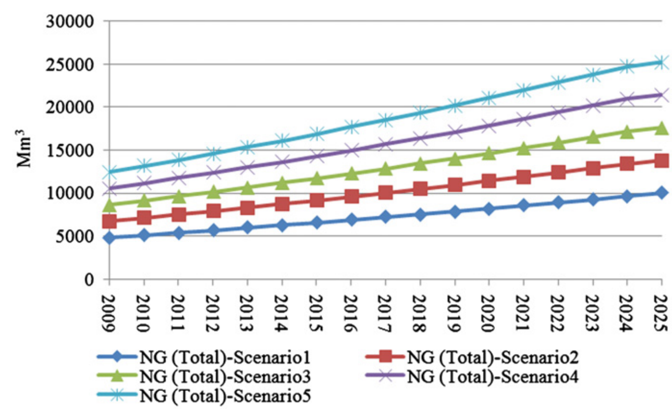


Fig. 9. The natural gas consumption in different scenarios.

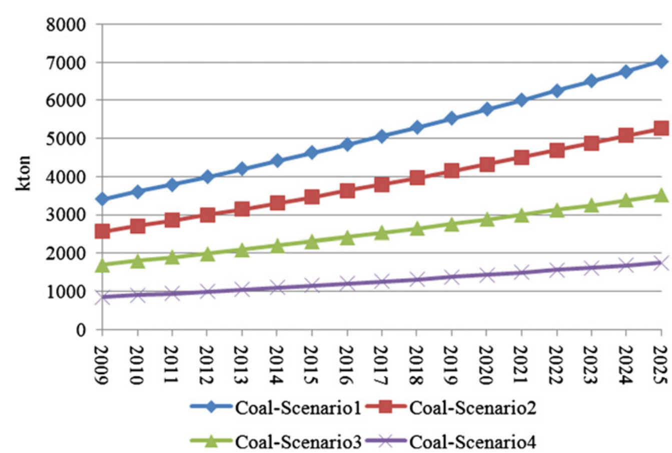


Fig. 10. The coal consumption in different scenarios.

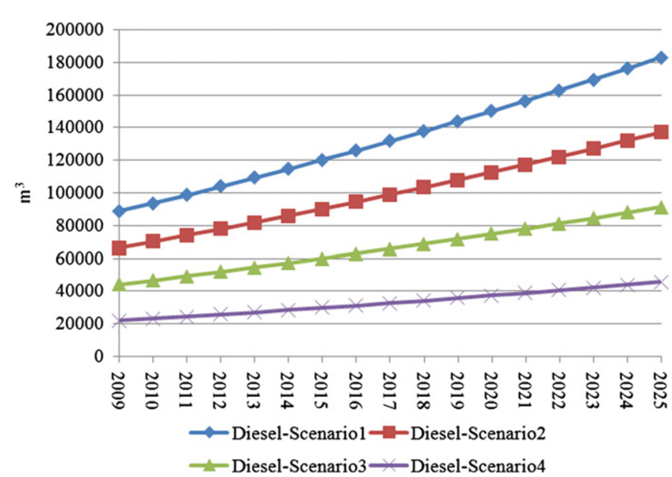


Fig. 11. The diesel oil consumption in different scenarios.

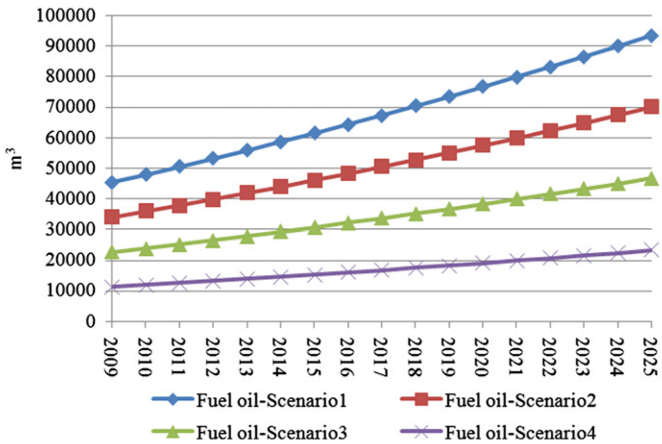


Fig. 12. The fuel oil consumption in different scenarios.

4.4. The predicted consumed fuel in each scenario.

The consumption of each types of fuel in each scenario is illustrated in Figs.9–12. As it can be seen in Fig. 9, natural gas has the highest consumption among all the other fuels and its consumption is steadily increasing by changing the scenarios from 1 to 5. Conversely, the consumption of coal, diesel and fuel oil is decreasing and in the last scenario their consumption is zero, thus it is not shown in their related figures.

Although the amount of natural gas consumption is increasing through scenarios from 1 to 5, considering the price of this fuel, it can be more economic and more environmental friendly.

5. Conclusion

In this article, five different scenarios were investigated that each of them proposes different combination of absorption and compression cooling systems for residential and commercial sectors. In the first scenario it was assumed that the pattern of cooling systems in future will not be affected and 100% of chillers in the sectors will be conventional compression systems. According to the results the fuel consumption with the current compression systems in 2025 will increase to 6308 Mm^3 for natural gas, 4419 kton for coal and 115 and 59 km^3 for diesel and fuel oil, respectively. On the other hand, it has been revealed that the consumption of natural gas will increase and meanwhile, the consumption of other fuels will decrease by retrofitting the absorption chillers instead of compression chillers. Finally, the last scenario in which all cooling systems in these sectors changed in 2025 to absorption cycle, the consumption of natural gas raising to 25,268 Mm^3.

Depends on the fuel resources, fuel prices and future policies of Malaysia, the best combination of absorption and compression cooling systems can be chosen by policymakers. Other factors that can affect decision for retrofitting of cooling systems are inflation rates, initial costs, maintenance costs and emission production by each system in each scenario.

Acknowledgements

The authors would like to acknowledge the Ministry of Higher Education of Malaysia and The University of Malaya, Kuala Lumpur, Malaysia for the financial support under UM.C/HIR/MOHE/ENG/15 (D000015–16001).

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